Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Environmental Science & Health

Do solar cycles explain the emergence of COVID-19? Neutron count comparison between the solar minima of 2008–2009 and 2019–2020

Tomoko Bell

Abstract

Cosmic rays are believed to be mutagenic and can stimulate virus mutation through point mutations. Neutron count on Earth ground stations is a reliable proxy to quantify cosmic ray flux. A previous study reported that the maximum flux of cosmic rays in November 2019 could be related to the emergence of COVID-19 (late November to early December). Using the latest neutron count data, this study investigated if the data from 2019 to 2020 could specifically explain the emergence of pandemic (COVID-19). The results indicate that there is no significant difference between the previous two last solar minima datasets (2008–2009 and 2019–2020; $n = 24$, $p = 0.60$). This suggests that the solar minima of 2019–2020 did not experience an increase in cosmic rays and the emergence of COVID-19 could not be solely explained by cosmic ray flux caused by solar cycles (space weather change).

Addresses

Water and Environmental Research Institute of the Western Pacific, University of Guam, UOG Station Mangilao, GU 96923, Guam

Corresponding author: Bell, Tomoko (tbell@uog.triton.edu)

Current Opinion in Environmental Science & Health 2022, **26:**100333

This review comes from a themed issue on **Occupational Safety and Health 2022: COVID-19 in environment: Treatment, Infectivity, Monitoring, Estimation**

Edited by **Manish Kumar**, **Ryo Honda**, **Prosun Bhattacharya**, **Dan Snow** and **Payal Mazumder**

For complete overview of the section, please refer to the article collection - Occupational Safety and Health 2022: COVID-19 in environment: Treatment, Infectivity, Monitoring, Estimation

https://doi.org/10.1016/j.coesh.2022.100333

Keywords

COVID-19, Solar cycles, Cosmic rays, Space weather, Neutron count.

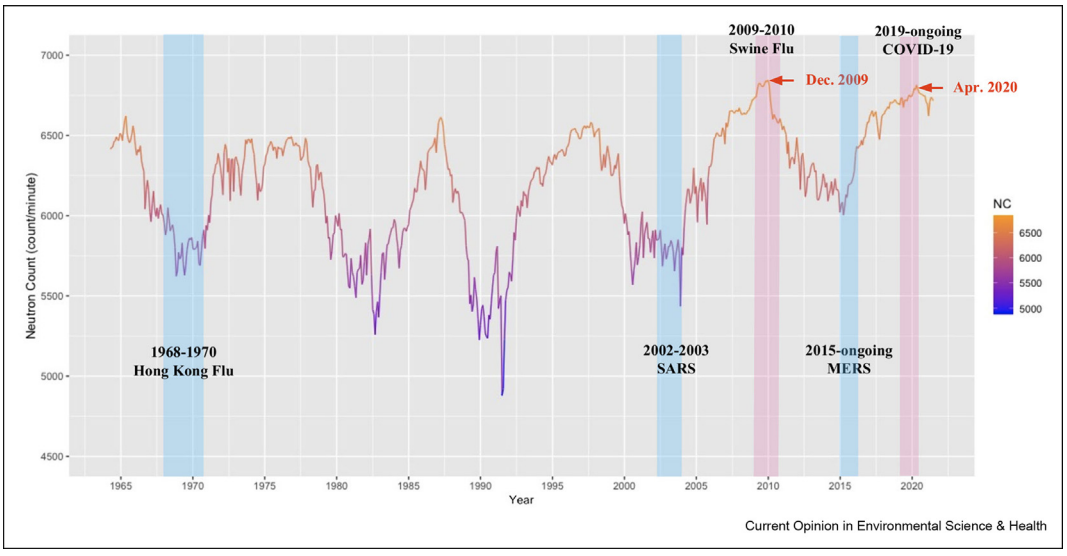
Introduction

COVID-19 is one of the pandemics of the modern age [1–5] that causes a severe upper respiratory tract syndrome [6,7]. The fatality rate of COVID-19 is estimated to be around 4% before the vaccination was available [8,9]. Although the exact origin of COVID-19 is not concluded yet, SARS-CoV-2 likely emerged from a horseshoe bat, hence, COVID-19 is considered as a zoonotic disease [10–15]. It is critical to investigate the trigger factor and rapid mutation of SARS-CoV-2 to prevent and prepare for possible future outbreaks. There are many studies that linked COVID-19 to environmental and metrological factors [16–24]. For example, Carleton et al. [19] reported that daily ultraviolet (UV) radiation lowers the cumulative daily growth rate of COVID-19 cases over the subsequent two and half weeks. Srivastava [24] stated gaseous pollutant (PM10, PM2.5, BC, NOx, SO_2, CO and VOCs concentration) and COVID-19 cases are positively correlated, and higher temperature is negatively correlated. These studies focusing on the transmission and environment factors are useful in terms of preventing the spread of COVID-19. However, questions still remain; what originally triggered the outbreak of COVID-19? Why does SARS-CoV-2 mutate rapidly? Would it be possible for us to control trigger factors of COVID-19?

Interestingly, one hypothesis is a correlation between pandemic outbreaks and the number of sunspots [[25–29]; Figure 1]. Wickramasinghe [27] suggested a 11-year cycle of sunspot minima and a 100-year cycle of sunspot deep minima decrease the solar magnetic field thus increases the total amount of mutagenic cosmic radiation that reaches Earth. On the other hand, Nasirpour et al. [29] stated that both solar maxima and minima could cause pandemics on Earth. They stated the same mechanism for solar minima as Wickramasinghe [27]. As to solar maxima, they suggest an increase in the solar magnetic field causing stronger solar winds that brings solar charged particles to Earth and cause point mutations in virus RNA.

Influence of cosmic rays might extend to viral hosts as well (e.g., human). It has been suggested an increase in cosmic rays influence virus replication in host organisms *via* NF-κB (protein complex regulating the expression of immune response genes) [30] as NF-κB can be activated in response to cosmic rays [30–34]. Zaporozhan and Ponomarenko [30] stated that any Earth organisms and their living conditions can be influenced by high-energy cosmic radiation comprised of electrons, protons, ultraviolet and gamma-rays. For

Figure 1



Possible correlations between historical pandemic and solar extrema. Neutron count data is collected from Oulu Cosmic Ray Station Neutron Monitor Database (https://cosmicrays.oulu.fi/). Historical pandemic data were identified from Piret and Boivin, (2020). If the years of each pandemic are close to solar minima or maxima, the years are shaded in blue or red, respectively. For ongoing pandemic (MERS and COVID-19), shaded boxes represent the start of the pandemic. Red arrows show the high peaks during 2009 and 2020.

example, NF-κB signaling in infected host cells plays an important role in differential regulation of influenza virus RNA synthesis. Indeed, many studies reported the correlation between solar cycles and influenza outbreaks [35–37]. This study evaluated the strength of cosmic rays reaching to Earth since 1964, which were measured by neutron count on an Earth ground station. The newest data was used (up to June 2021) to find the possible relation among Sun, Earth, and the ongoing COVID-19 pandemic. The focus of study is to test; if the amount of mutagenic cosmic rays measured by neutron count on an Earth ground station is the highest during 2019–2020 and can explain the outbreak of COVID-19.

Methods

Data

The cosmic ray data from 1964 to 2021 was extracted from Oulu Cosmic Ray Station Neutron Monitor Database (URL: https://cosmicrays.oulu.fi/). It has been reported that the neutron monitor at Sodankylä Geophysical Observatory located in Finland (67° 22′ N, 26° 38′ E) is one of the most stable and reliable stations of the World Neutron Monitor Network [38]. Neutron count (average count per minute) is a method to quantify cosmic rays (i.e., proxy for cosmic ray flux). As cosmic rays collide with particles in the Earth's atmosphere, they create secondary particles such as neutrons [39–43]. Historical pandemic data was identified from Piret and Boivin [44] and Liu et al. [2].

Statistical analysis

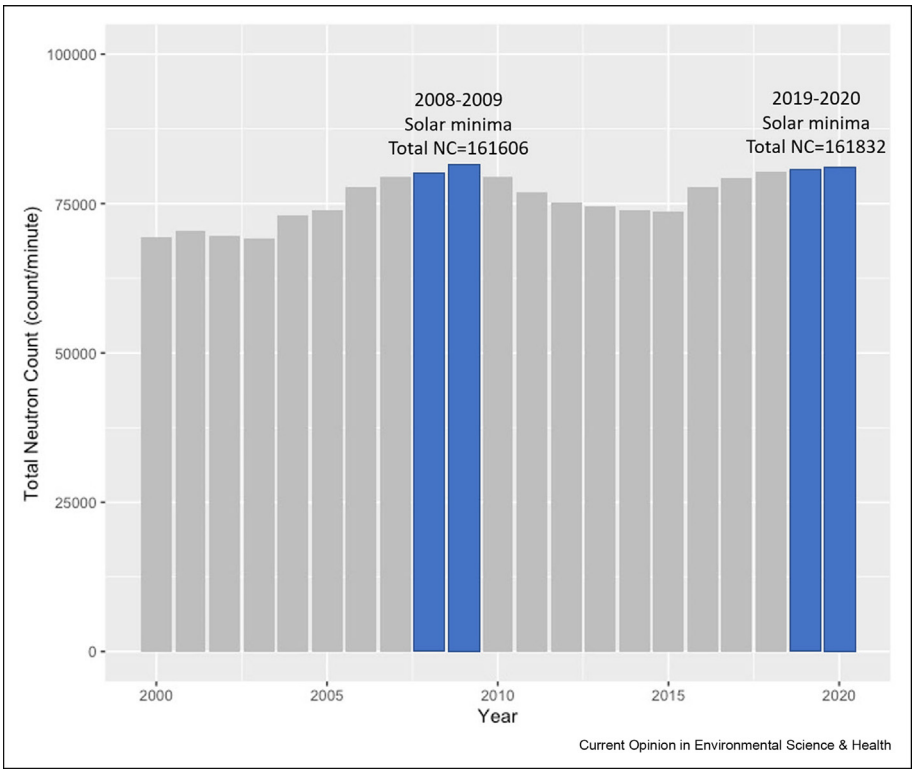
The difference between the dataset of 2008–2009 and 2019–2020 was tested using Student's t-test. For linear regression analysis, the past 24 month data from the highest peak during 2008–2009 and 2019–2020 were analyzed to investigate the neutron increase trend. The trend of neutron data was calculated by linear regression followed by ANCOVA to test if the slopes of these two linear equations are significantly different. All the calculations were conducted using R ver. 3.6.1 (R Core-Team, 2019).

Results

Based on the neutron count (NC) per minute, cosmic rays peaked in April 2020 ($NC = 6813$) which was close to the start of the pandemic. However, there was a peak in December 2009 ($NC = 6844$), and its value was slightly higher than the data in April 2020 (Figure 1) and indeed December 2009 was the highest since 1964. Therefore, this study focused on the detailed difference between the year of last two solar minima 2008–2009 and 2019–2020 to compare how these two high neutron count peaks were different.

The duration of high peak ($NC > 6800$) lasted for nine months during 2008–2009 (from April 2009–December 2009) while it lasted only one month (April 2020) during 2019–2020. The cumulative neutron count were 161,606 and 161,832 for 2008–2009 and 2019–2020 (Figure 2) respectively. There were no significant

Figure 2



Comparison of neutron count from two recent solar minima: 2008–2009 and 2019–2020. There were no significant differences within these two datasets (monthly data of 2008–2009 and 2019–2020; $n = 24$, $p = 0.60$).

differences among these two datasets (monthly data of 2008–2009 and 2019–2020; $n = 24$, $p = 0.60$).

The regression analysis showed that the overall the neutron count is increasing since 1964 to present (Figure 3a). The increase was sharper during 2008–2009 compared to the one during 2019–2020 (Figure 3b). The liner equations for the data from 2008 to 2009, and the data from 2019 to 2020 were $y = 11x + 6596$ ($R^2 = 0.93$, $p < 0.001$), and $y = 4x + 6675$ ($R^2 = 0.65$, $p < 0.001$), respectively. This difference in these two slopes was statistically significant as a result of ANCOVA (F (1, 44) = 60.37, $p < 0.001$).

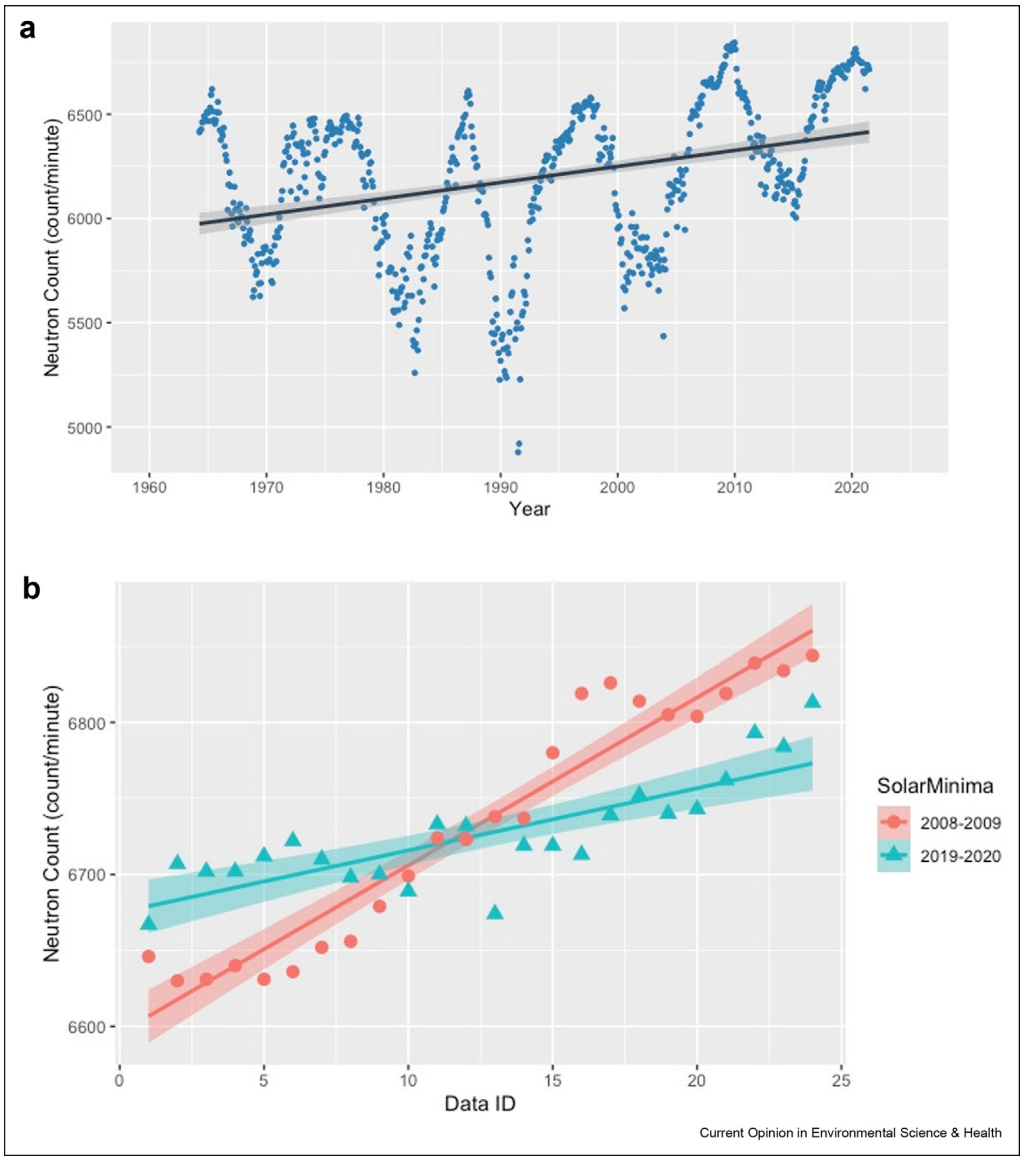
Discussion

The cosmic ray peak detected from this analysis shared similarity with the neutron count from 1962 to 2019 reported by Wickramasinghe [27]. In their study, neutron count from the Moscow Neutron Monitor showed the maximum flux of cosmic rays reaching Earth in November 2019, and they reported it was the highest record since 1962. Therefore, they concluded that the maximum flux of cosmic rays in November 2019 correlated with the emergence of COVID-19 (late November to early December). On the contrary, this study extended the time period of the data from 2019 to 2021, and found that April 2009 was indeed higher than 2019. Thus, the maximum flux of cosmic rays could not be directly related to the emergence of COVID-19. Such a regional difference in the cosmic ray flux can be simply explained by altitude and geomagnetic latitude [26].

Although our analysis found that the cumulative neutron count in 2008–2009 showed a lower value than 2019–2020, Student's t-test showed that there was no statistically significant difference between the data of 2008–2009 and 2019–2020. The linear regression analysis indicated that neutron count showed an increasing trend since the early 1960's, and the increase was indeed significantly sharper during 2008–2009 compared to 2019–2020 (F (1, 44) = 60.37, $p < 0.001$). Therefore, the solar minima of 2019–2020 is not causing a sharper increase in neutron count compared to the previous solar minima of 2008–2009. From the discussion above, there is no evidence to support that the solar minima of 2019–2020 experienced a significant increase in neutron count, which is the proxy for cosmic rays.

The direct monitoring of solar irradiance from space missions support that there is no significant difference between the 2008–2009 and 2019–2020 solar minima as well. Finsterle et al. [45] reported that two NASA

Figure 3



Linear increase in neutron count from 1964 (Figure (a)) and from 2008–2009 and 2019–2020 (Figure (b)). Neutron count data is collected from Oulu Cosmic Ray Station Neutron Monitor Database (https://cosmicrays.oulu.fi/). The difference in the two slopes (2008–2009 and 2019–2020) was statistically significant as a result of ANCOVA (F (1, 44) = 60.37, $p < 0.001$).

space missions measuring solar irradiance, Precision Monitoring of Solar Variability (PREMOS), and Variability of Irradiance and Gravity Oscillations (VIRGO), showed no significant change (i.e., -0.17 ± 0.29 W/m^2) during the two most recent solar minima in 2008–09 and 2019–20. Thus, it is reasonable to assume that cosmic ray data driven by solar minima cannot solely provide enough evidence to treat 2019–20 peak differently from 2008 to 09 peak to discuss the emergence of COVID-19. This does not deny the possible effects of cosmic rays on COVID-19 as many studies report the correlations between solar cycles and pandemics (Figure 1). However, this study suggests that there must exist other factors such as climatology and/or environmental variables that triggered the emergence of COVID-19.

For example, the variables related to bat ecology should be considered. The surface temperature anomaly data from NOAA (URL:https://www.ncdc.noaa.gov/cag/global/time-series) reports a sharp temperature increase trend from 2010 to 2019. This indicates that the temperature increase is driven by anthropogenic factors such as CO_2 emission as reported from previous studies

[45–48]. According to the EPA (URL: https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature),global average surface temperature has risen at an average rate of 0.09 °C per decade since 1901 while it is 0.17 °C per decade since 1979. Also, IPCC [49] reports the increase in global average temperature over the course of this century levels up to at least 2 °C relative to 1850–1900. Intriguingly, Beyer et al. [12] reported that the rapid temperature increase shifted the global distribution of bats. They reported that the southern Chinese Yunnan province and neighboring regions in Myanmar and Laos form a global hotspot of climate change-driven increase in bat richness. Also, Wu [50] stated that bat species distributions in China have primarily shifted northward due to temperature increases for the past 50 years. As mentioned in Section 1, SARS-CoV-2, likely emerged from bats. Liu et al. [51] and Wacharapluesadee et al. [52] reported that bat-origin RaTG13 virus is currently the most phylogenetically related virus to SARS-CoV-2. Letko et al. [53] stated that bats carry 10,756 reported viruses from at least 28 diverse viral families and they stated that Ebola virus, Marburg virus, Nipah virus, Hendra virus, SARS-CoV, MERS-CoV, and SARS-CoV-2, are all linked to various bat species.

Identifying the dominant environmental or climatological variables that triggered the emergence of COVID-19, is beyond the scope of this article; however, the factor that altered bat distribution should be further investigated. It should be also noted that the increasing trend in neutron count will continue until the end of 2053 owing to decreasing in solar activity [54], which allows mutagenic radiation to penetrate to Earth. The latest IPCC full report [49] is predicting a global temperature increase of 1.2–3.0 °C by 2060. In case the combination of space weather and Earth's climatology and environmental variables were the triggers of severe pandemic, more pandemics during 2030–31, 2041–42, and 2052–2053 are possible scenarios.

Conclusion

This study suggests that the emergence of the COVID-19 pandemic cannot be explained solely by solar minima (space weather) and is related to climatology and environmental variables on Earth. For example, redistribution of the bat population owing to surface temperature changes or a combination of such a factor and space weather can be considered. To further elucidate the molecular mechanisms of rapid SARS-CoV-2 mutation and cosmic radiation, laboratory experiments will be needed to support the relevance between solar cycles and virus point mutation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Acknowledgement

Author appreciates Oulu University for the use of Cosmic Ray Station Neuron Monitor Database, also NOAA for the surface temperature anomaly data. This research was supported by JSPS overseas research fellowship.

References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest

1. Cruickshank M, Shaban RZ: **COVID-19: lessons to be learnt from a once-in-a-century global pandemic**. *J Clin Nurs* 2020, **29**.
2. Liu YC, Kuo RL, Shih SR: **COVID-19: the first documented coronavirus pandemic in history**. *Biomed J* 2020, **43**.
3. Feehan J, Apostolopoulos V: **Is COVID-19 the worst pandemic?** *Maturitas* 2021, **149**.
4. Nalbandian A, Sehgal K, Gupta A, Madhavan MV, McGroder C, Stevens JS, Cook JR, Nordvig AS, Shalev D, Sehrawat TS, *et al.*: **Post-acute COVID-19 syndrome**. *Nat Med* 2021, **27**.
5. Wang C, Wang Z, Wang G, Lau JYN, Zhang K, Li W: **COVID-19 in early 2021: current status and looking forward**. *Signal Transduct Target Ther* 2021, **6**.
6. Platto S, Xue T, Carafoli E: **COVID19: an announced pandemic**. *Cell Death Dis* 2020, **11**.
7. Gibson PG, Qin L, Puah SH: **COVID-19 acute respiratory distress syndrome (ARDS): clinical features and differences from typical pre-COVID-19 ARDS**. *Med J Aust* 2020, **213**.
8. Arshad N, Naqi SA, Kumar J: **A novel coronavirus transmission from China to Pakistan via different countries; A review**. *Prof Med J* 2020, **27**.
9. Sorci G, Faivre B, Morand S: **Explaining among-country variation in COVID-19 case fatality rate**. *Sci Rep* 2020, **10**.
10. Dhama K, Patel SK, Sharun K, Pathak M, Tiwari R, Yatoo MI, Malik YS, Sah R, Rabaan AA, Panwar PK, *et al.*: **SARS-CoV-2 jumping the species barrier: zoonotic lessons from SARS, MERS and recent advances to combat this pandemic virus**. *Trav Med Infect Dis* 2020, **37**.
11. Lau SKP, Luk HKH, Wong ACP, Li KSM, Zhu L, He Z, Fung J, Chan TTY, Fung KSC, Woo PCY: **Possible bat origin of severe acute respiratory syndrome coronavirus 2**. *Emerg Infect Dis* 2020, **26**.
12. Beyer RM, Manica A, Mora C: **Shifts in global bat diversity suggest a possible role of climate change in the emergence of SARS-CoV-1 and SARS-CoV-2**. *Sci Total Environ* 2021, **767**.
13. MacKenzie JS, Smith DW: **COVID-19: a novel zoonotic disease caused by a coronavirus from China: what we know and what we don't**. *Microbiol Aust* 2020, **41**.
14. Mazinani M, Rude BJ: **The novel zoonotic Coronavirus disease 2019 (COVID-19) pandemic: health perspective on the outbreak**. *J Healthc Qual Res* 2021, **36**.
15. Rulli MC, D'Odorico P, Galli N, Hayman DTS: **Land-use change and the livestock revolution increase the risk of zoonotic coronavirus transmission from rhinolophid bats**. *Nat Food* 2021, **2**.
16. Makama EK, Lim HS: **Effects of location-specific meteorological factors on COVID-19 daily infection in a tropical climate: a case of kuala lumpur, Malaysia**. *Adv Meteorol* 2021, **2021**, 6675943.
17. Sagripanti JL, Lytle CD: **Estimated inactivation of coronaviruses by solar radiation with special reference to COVID-19**. *Photochem Photobiol* 2020, **96**.

18. Sarkodie SA, Owusu PA: **Impact of meteorological factors on COVID-19 pandemic: evidence from top 20 countries with confirmed cases**. *Environ Res* 2020, **191**.

19. Carleton T, Cornetet J, Huybers P, Meng KC, Proctor J: **Global evidence for ultraviolet radiation decreasing COVID-19 growth rates**. *Proc Natl Acad Sci U S A* 2020, **118**.

20. Damette O, Mathonnat C, Goutte S: **Meteorological factors against COVID-19 and the role of human mobility**. *PLoS One* 2021, **16**.

21. Guo C, Bo Y, Lin C, Li HB, Zeng Y, Zhang Y, Hossain MS, Chan JWM, Yeung DW, Kwok K on, *et al.*: **Meteorological factors and COVID-19 incidence in 190 countries: an observational study**. *Sci Total Environ* 2021, **757**.

22. Kang D, Ellgen C, Kulstad E: **Possible effects of air temperature on COVID-19 disease severity and transmission rates**. *J Med Virol* 2021, **93**.

23. Ma Y, Pei S, Shaman J, Dubrow R, Chen K: **Role of meteorological factors in the transmission of SARS-CoV-2 in the United States**. *Nat Commun* 2021, **12**.

24. Srivastava A: **COVID-19 and air pollution and meteorology-an intricate relationship: a review**. *Chemosphere* 2021, **263**.

25. * Janani T: **Relationship between sunspots and COVID-19 - a prof for panspermia**. *Int J Eng Technol* 2020, **7**.
This paper explained that mechanism why Earth's atmosphere receives more cosmic rays during solar minimum. It also suggested that cosmic rays during the solar minimum cause mutation in species and make them vulnerable to pandemics.

26. * Navia CE: **On the occurrence of historical pandemics during the grand solar minima**. *Eur J Appl Physiol* 2020, **2**.
This paper examined the difference of "antigenic-shift" and "antigenic-drift" of virus. They showed the possibility of "antigenic-shift" due to neutrons from cosmic rays that cause a new type of viral strains.

27. * Wickramasinghe NC: **Is the 2019 novel coronavirus related to a spike of cosmic rays?** *Adv Genetic* 2020, **106**.
This study stated that the flux of cosmic rays reaching Earth in 2019 is at a maximum since 1962 which coincided with the start of COVID-19. Also, it reported that cosmic rays cause point mutations that can lead to the emergence of new or modified viruses.

28. * Wu J: **The sunspot cycle leads to origin and epidemic mechanism of novel coronavirus COVID-19**. *Nat Sci* 2020, **12**.
This study reported that natural mutation of the virus is very slow, however it can be accelerated by the formation of light vortex field effects (aura) by sunlight and cosmic rays. It emphasized that the Sun plays a significant role in life on the Earth.

29. * Nasirpour MH, Sharifi A, Ahmadi M, Jafarzadeh Ghoushchi S: **Revealing the relationship between solar activity and COVID-19 and forecasting of possible future viruses using multi-step autoregression (MSAR)**. *Environ Sci Pollut Res* 2021, **28**.
They conducted wavelet and autoregression analysis using sunspot data to predict past pandemics and forecast the future time of possible virus generation. This study concluded that pandemic could happen during solar extrema.

30. Zaporozhan V, Ponomarenko A: **Mechanisms of geomagnetic field influence on gene expression using influenza as a model system: basics of physical epidemiology**. *Int J Environ Res Publ Health* 2010, **7**.

31. Baumstark-Khan C, Hellweg CE, Arenz A, Meier MM: **Cellular monitoring of the nuclear factor κB pathway for assessment of space environmental radiation**. *Radiat Res* 2005, **164**.

32. Hellweg CE, Dilruba S, Adrian A, Feles S, Schmitz C, Berger T, Przybyla B, Briganti L, Franz M, Segerer J, *et al.*: **Space experiment "cellular responses to radiation in space (CellRad)": hardware and biological system tests**. *Life Sci Space Res* 2015, **7**.

33. Hellweg CE, Langen B, Klimow G, Ruscher R, Schmitz C, Baumstark-Khan C, Reitz G: **Up-stream events in the nuclear factor κB activation cascade in response to sparsely ionizing radiation**. *Adv Space Res* 2009, **44**.

34. Zhang Y, Maria-Villanueva M, Krieger S, Ramesh GT, Neelam S, Wu H: **Transcriptomics, NF-ĸB pathway, and their potential spaceflight-related health consequences**. *Int J Mol Sci* 2017, **18**.

35. Michalettou TD, Michalopoulos I, Costes SV, Hellweg CE, Hada M, Georgakilas AG: **A meta-analysis of the effects of high-let ionizing radiations in human gene expression**. *Life* 2021, **11**.

36. Hoyle F, Wickramasinghe NC: **Sunspots and influenza**. *Nature* 1990, **343**.

37. Yeung JWK: **A hypothesis: sunspot cycles may detect pandemic influenza A in 1700-2000 A.D.** *Med Hypotheses* 2006, **67**.

38. Qu J: **Is sunspot activity a factor in influenza pandemics?** *Rev Med Virol* 2016, **26**.

39. Usoskin IG, Mursula K, Kangas J, Gvozdevsky B: **On-line Database of cosmic ray intensities**. In *Proceedings of ICRC*; 2001:1–4.

40. Nakamura T: **Cosmic-ray neutron spectrometry and dosimetry**. *J Nucl Sci Technol* 2008, **45**.

41. Bütikofer R: **Ground-based measurements of energetic particles by neutron monitors**. In *Solar Particle Radiation Storms Forecasting and Analysis*. Springer; 2018:95–111.

42. Nuntiyakul W, Sáiz A, Ruffolo D, Mangeard PS, Evenson P, Bieber JW, Clem J, Pyle R, Duldig ML, Humble JE: **Bare neutron counter and neutron monitor response to cosmic rays during a 1995 latitude survey**. *J Geophys Res Sp Phys* 2018, **123**.

43. Dawn S, Chatterjee S, Chakrabarty S, Mufti S, Bakshi AK, Sapra BK: **Cosmic ray neutron spectrometry and dosimetry at high altitude research laboratory, gulmarg, kashmir, India**. *Radiat Phys Chem* 2021, **185**.

44. Piret J, Boivin G: **Pandemics throughout history**. *Front Microbiol* 2021, **11**.

45. Finsterle W, Montillet JP, Schmutz W, Šikonja R, Kolar L, Treven L: **The total solar irradiance during the recent solar minimum period measured by SOHO/VIRGO**. *Sci Rep* 2021, **11**.

46. Delworth TL, Mahlman JD, Knutson TR: **Changes in Heat Index associated with CO2-induced global warming**. *Clim Change* 1999, **43**.

47. Skytt T, Nielsen SN, Jonsson BG: **Global warming potential and absolute global temperature change potential from carbon dioxide and methane fluxes as indicators of regional sustainability – a case study of Jämtland, Sweden**. *Ecol Indicat* 2020, **110**.

48. Yoro KO, Daramola MO: **CO2 emission sources, greenhouse gases, and the global warming effect**. In *Advances in carbon capture*. Woodhead Publishing; 2020:3–28.

49. IPCC (Intergovermental Panel on Climate Change): Climate Change 2021 The Physical Science Basis**.** https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf.

50. Wu J: **Detection and attribution of the effects of climate change on bat distributions over the last 50 years**. *Clim Change* 2016, **134**.

51. * Liu K, Pan X, Li L, Yu F, Zheng A, Du P, Han P, Meng Y, Zhang Y, Wu L, *et al.*: **Binding and molecular basis of the bat coronavirus RaTG13 virus to ACE2 in humans and other species**. *Cell* 2021, **184**.
Bat-origin RaTG13 is currently the most phylogenetically related virus to SARS-CoV-2. The authors evaluated binding of RaTG13 to 24 human ACE2 orthologs. This study identified that residue 501 plays a significant role in determining the potential host range of RaTG13.

52. * Wacharapluesadee S, Tan CW, Maneeorn P, Duengkae P, Zhu F, Joyjinda Y, Kaewpom T, Chia WN, Ampoot W, Lim BL, *et al.*: **Evidence for SARS-CoV-2 related coronaviruses circulating in bats and pangolins in Southeast Asia**. *Nat Commun* 2021, **12**.

This study sequenced a total of 100 horseshoe bats captured from the cave in Thailand, and they identified a new gene named RacCS203 which had a high similarity to RmYN02 found from bats in China. They provided evidence that SARS-CoV-2 related coronaviruses are actively circulating among bats in Southeast Asia.

53. * Letko M, Seifert SN, Olival KJ, Plowright RK, Munster VJ: **Bat-borne virus diversity, spillover and emergence**. *Nat Rev Microbiol* 2020, **18**.

In this review paper, they explained the uniqueness of bat virus, viral-spill over events to humans, and molecular mechanisms of how bat viruses enter into host species. They stated that the natural mutations of SARS-CoV have low mutation rates associated with 3′−5′ exoribonuclease proofreading activity.

54. Zharkova V: **Modern Grand Solar Minimum will lead to terrestrial cooling**. *Temperature* 2020, **7**.